Step-by-step solution

As noted, we use the convention that forces to the right are positive and those to the left are negative. A more rigorous approach would be to calculate the vector components of these forces using the cosine of 0° for the frictional force and the cosine of 180° for the pushing force. The result would be *X* components of 18.0 N and −34.0 N (the same conclusion we reached via inspection and convention). Many instructors prefer this approach. It does not change the answer to the problem, but the component method is more rigorous, and is required to solve more difficult problems.

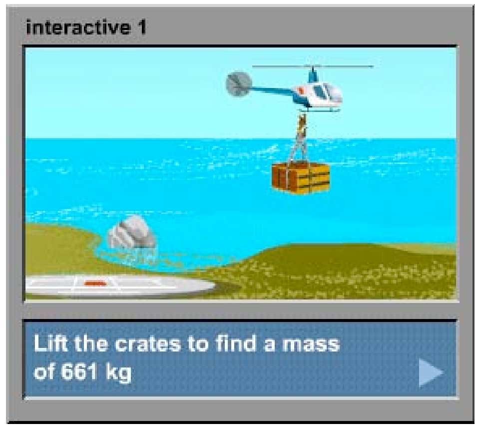
Step	Reason
1. $\Sigma \mathbf{F} = \mathbf{F}_{push} + \mathbf{F}_{friction}$	net horizontal force
2. $\Sigma F = -34.0\text{ N} + 18.0\text{ N}$ $\Sigma F = -16.0\text{ N}$	enter values and add
3. $\Sigma F = ma$	Newton's second law
4. $a = \Sigma F/m$	solve for a
5. $a = (-16.0\text{ N}) / (15.0\text{ kg})$	enter values
6. $a = -1.07\text{ m/s}^2$	division

5.17 - Interactive problem: lifting crates

The helicopter on the right is being used as a scale, making it one of the more expensive scales in the world, we suspect. This simulation includes three crates; each has a slightly different mass. Your assignment is to find the crate with a mass of 661 kg. Do this by lifting each crate with the helicopter and noting the acceleration. The helicopter lifts each crate with a force of 10,748 N via the tension in the cable. The resulting acceleration of each crate will let you calculate its mass.

Click on the graphic to start the simulation. To determine the answer, drag the helicopter to each of the three crates and press GO to make the helicopter lift the crate. Record the acceleration of each crate and use the acceleration to calculate the mass. When you have found the crate with a mass of 661 kg, select it by clicking on it. The simulation will tell you whether you clicked on the correct one.

If you cannot solve the problem, review Newton's second law and the section on weight.



5.18 - Friction

Friction: **A force that resists the motion of one object sliding past another.**

If you push a cardboard box along a wooden floor, you have to push to overcome the force of friction. This force makes it harder for you to slide the box. The force of friction opposes any force that can cause one object to slide past another. There are two types of friction: static and kinetic. These forces are discussed in more depth in other sections. In this section, we discuss some general properties of friction.

Friction between the buffalo's back and the tree scratches an itch.

The amount of friction depends on the materials in contact. For example, the box would slide more easily over ice than wood. Friction is also proportional to the normal force. For a box on the floor, the greater its weight, the greater the normal force, which increases the force of friction.

Humans expend many resources to combat friction. Motor oil, Teflon™, WD-40™, Tri-Flo™ and many other products are designed to reduce this force. However, friction can be very useful. Without it, a nail would slip out of a board, the tires of a car would not be able to "grip" the road, and you would not be able to walk.

Friction exists even between seemingly smooth surfaces. Although a surface may appear smooth, when magnified sufficiently, any surface will look bumpy or rough, as the illustration in Concept 2 on the right shows. The magnified picture of the "smooth" crystal reveals its microscopic "rough" texture. Friction is a force caused by the interaction of molecules in two surfaces.

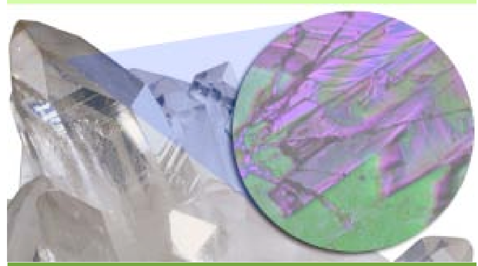
You might think you can defeat friction by creating surfaces that are highly polished. Instead, you may get an effect called *cold welding*, in which the two highly polished materials fuse together. Cold welding can be desirable, as when an aluminum connector is crimped onto a copper wire to create a strong electrical connection.

Objects can also move in a fashion that is called *slip and slide*. They slide for a while, stick, and then slide some more. This phenomenon accounts for both the horrid noise generated by fingernails on a chalkboard and the joyous noise of a violin. (Well, joyous when played by some, chalkboard-like when played by others.)

concept 1

Friction
Force that opposes "sliding" motion
Varies by materials in contact
Proportional to normal force

concept 2



Friction
Microscopic properties determine friction force

5.19 - Static friction

Static friction: A force that resists the sliding motion of two objects that are stationary relative to one another.

Imagine you are pushing a box horizontally but cannot move it due to friction. You are experiencing a response force called static friction. If you push harder and harder, the amount of static friction will increase to exactly equal − but not exceed − the amount of horizontal force you are supplying. For the two surfaces in contact, the friction will increase up to some maximum amount. If you push hard enough to exceed the maximum amount of static friction, the box will slide.

For instance, let’s say the maximum amount of static friction for a box is 30 newtons. If you push with a force of 10 newtons, the box does not move. The force of static friction points in the opposite direction of your force and is 10 newtons as well. If it were less, the box would slide in the direction you are pushing. If it were greater, the box would accelerate toward you. The box does not move in either direction, so the friction force is 10 newtons. If you push with 20 newtons of force, the force of static friction is 20 newtons, for the same reasons.

You keep pushing until your force is 31 newtons. You have now exceeded the maximum force of static friction and the box accelerates in the direction of the net force. The box will continue to experience friction once it is sliding, but this type of friction is called kinetic friction.

concept 1

Static friction
Force opposing sliding when no motion
Balances "pushing" force until object slides
Maximum static friction proportional to:
· coefficient of static friction

· normal force

Static friction occurs when two objects are motionless relative to one another. Often, we want to calculate the maximum amount of static friction so that we know how much force we will have to apply to get the object to move. The equation in Equation 1 enables you to do so. It depends on two values. One is the normal force, the perpendicular force between the two surfaces. The second is called the *coefficient of static friction*.

Engineers calculate this coefficient empirically. They place an object (say, a car tire) on top of another surface (perhaps ice) and measure how hard they need to push before the object starts to move. Coefficients of friction are specific to the two surfaces. Some examples of coefficients of static friction are shown in the table in Equation 2.

You might have noticed a fairly surprising fact: The amount of surface area between the two objects does not enter into the calculation of maximum static friction. In principle, whether a box of a given mass has a surface area of one square centimeter or one square kilometer, the